Design and Performance Analysis of a Honeycomb-Shaped Brass Alloy Catalytic Converter for Sustainable Emission Control in 4-Stroke Engines

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Keywords:

- Brass-Based Catalytic Converter;
- Honeycomb shaped;
- Sustainability;
- Cost-effective material;
- Emission Reduction;
- 4 stroke engine;

Abstract: The automotive sector is a cornerstone of economic growth and technological innovation, yet it remains a significant contributor to global greenhouse gas (GHG) emissions, responsible for 24% of the worldwide total. It is actively exploring sustainable solutions to reduce its carbon footprint, including the development of advanced and economical catalytic converter technologies. Catalytic converters reduce harmful emissions by promoting efficient combustion, but their reliance on expensive and scarce metals like palladium and rhodium drives the search for alternative materials. Identifying suitable materials that balance ecological significance with productive outcomes, while ensuring sustainability and cost-effectiveness, remains a persistent challenge. To address this issue, this research has been conducted to explore the feasibility of using Honey comb shaped Brass alloy catalytic converter as cost-effective and sustainable substitute. Experimental data demonstrated that Brass-based catalytic converter reduces HC emissions by up-to 23.48%, CO level lowered by 20.96% and CO2 concentration increased by 39.96% compared to conventional catalyst converter. Brass's affordability and sustainability enable wider adoption and frequent replacement of worn-out converters, ensuring consistent emission control. These findings position Brass as a viable alternative to traditional precious-metal-based catalysts, advancing the automotive sector's transition to net-zero emissions. This research aligns with regulatory goals and global efforts to reduce GHG emissions, paving the way for greener transportation solutions.

1. Introduction

The rise in vehicle emissions and air pollution has necessitated innovative solutions for controlling harmful pollutants such as carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides (NOx). Brass-based catalytic converters (NBCCs) have emerged as a cost-effective alternative to traditional platinum group metals (PGMs), leveraging materials like copper,

nickel oxide, and cerium-based oxides for efficient emission reduction. By integrating advanced catalytic technologies with diesel particulate filters (DPFs) and promoting sustainable biofuels, these converters offer a promising path toward cleaner transportation and achieving global net-zero emission goals(1). The primary causes of air pollution are vehicle exhaust and fossil fuel burning. Controlling harmful emissions such as CO, NOx, and HC is an essential task for future generations (2). However, researchers are exploring alternative and potentially more sustainable solutions. Mukherjee et al. n.d. explored that NBCCs can achieve a 40% reduction in hydrocarbons (HC) and a 35% reduction in carbon monoxide (CO) emissions from a four-cylinder diesel engine (3) .Kritsanaviparkporn et al. 2021 have proposed a solution using a combination of metal catalysts like cerium oxide on ceramic pellets, achieving good conversion rates for HC, CO, and NOx at a lower cost (4). Ingle et al. 2023 found that copper works as a catalyst for catalytic converter, though being not a noble metal. Kalpana Joshi used catalytic converter with the coating of nickel oxide nanomaterial on the copper plates as catalyst. (5). Several patents showcase established and innovative catalytic converter technologies. These include patents for catalysts using different materials, high-efficiency NO converters, and combined converter-DPF systems (6,7). The utilization of sustainable biofuels can shape a CO2 life cycle, which from a social point of view can reduce CO2 emission (8). Additionally, Brass is a denser material than some commonly used options. While this doesn't necessarily affect performance, it can add weight to the converter, potentially affecting a vehicle's overall balance and fuel efficiency (9). Another challenge lies in optimizing the design and manufacturing processes for Brass converters. Ensuring compatibility with other components within the exhaust system and developing efficient manufacturing techniques (10).

The honeycomb structure was selected based on its established benefits in catalytic applications, including increased surface area for gas-catalyst interaction and improved mass transfer efficiency, as demonstrated by Heck et al. (11). Honeycomb-based catalytic substrates offer superior thermal stability and structural integrity under high-temperature exhaust conditions, as demonstrated in the studies by Twigg (12). This ensures long-term catalytic efficiency and reliability in automotive applications. Studies have shown that honeycomb-based catalytic converters outperform alternative designs in pollutant conversion efficiency and structural resilience (13) The honeycomb structure optimizes catalytic reaction kinetics by ensuring maximum exposure of pollutants to the catalytic material, as supported by Roy et al. (14).

The aim of this study is to advance sustainable and cost-effective catalytic converter technologies to address the global challenge of vehicle emissions, contributing to net-zero goals. The objective includes optimizing catalytic converter designs to reduce emission, while addressing challenges in material compatibility and cost reduction. This research aims to contribute to cleaner transportation solutions and sustainable environmental practices.

2. Methodology & Construction

This research focuses on the design, fabrication, and experimental evaluation of a Honey comb shaped Brass-based catalytic converter integrated into a 4-stroke petrol engine to mitigate exhaust emissions. The process is carefully structured into three interconnected phases:

designing the system, fabricating the catalytic core and exhaust assembly, and conducting experimental analyses to validate its effectiveness. The initial phase centered around the design process, where the catalytic converter's dimensions, structure, and configuration were determined to seamlessly fit into a standard vehicle exhaust system. Using SolidWorks, the

Figure 1 SolidWorks Model

primary design of the Brass core was developed (Figure 01). After finalizing the design, a 3D-printed model was produced to serve as a prototype and to create the mold used in the casting process. Following the design phase, the fabrication process began. High-quality Brass material was chosen as the primary component for the catalytic core. A casting process was employed to produce the core, utilizing the mold generated from the 3D-printed prototype. The Brass was melted at a controlled temperature and carefully poured into the mold. Once the casting cooled, the raw Brass core underwent a series of machining processes (grinding, drilling, and reshaping) to achieve the desired dimensions and surface finish. Additionally, a bend pipe was fabricated and integrated into the exhaust system, connecting the Brass core to the engine's exhaust manifold. The fabricated Brass-based catalytic converter was installed within the muffler assembly of a 4-stroke petrol engine(Figure 02). This configuration retained the conventional muffler design while discreetly housing the new catalytic chamber. The Brass core was securely mounted inside the muffler This arrangement facilitated seamless gas flow while ensuring maximum exposure of pollutants to the catalytic material.

The final phase involved experimental validation of the Brass-based catalytic converter's performance. A comprehensive experimental setup was designed to compare the pollutant reduction efficiency of the Brass-based system against a conventional catalytic converter. The testing was conducted using a 4-stroke petrol engine(Figure 03), with key performance parameters such as exhaust pollutant concentrations, engine speed, and temperature variations being measured. Specification of engine is shown in Table 01.The engine was equipped with a

Table 1 Specification of Four stroke Engine

Types of vehicles	*Model name*	*Engine bore*	*Engine stroke*	*Cylinder*	*Stroke*	*Fuel used*	*Swept volume*	*Fuel tank*	*Air fuel ratio*
CNG	BAJAJ RE 2010	75mm	79mm	1	4	Petalite	174cc	8L	15:1

non-contact tachometer to monitor the rotational speed of the engine's shaft, and an exhaust gas analyzer was used to measure the concentrations of primary pollutants, including CO, CO_2 , and HC. Both devices were connected to an alternating current (AC) power source to ensure consistent and accurate data recording throughout the tests. The experimental procedure began with baseline measurements using the conventional catalytic converter. This step established a reference for pollutant emissions under standard conditions. Next, the Brass-based catalytic converter was installed, and the same set of measurements was repeated. The testing was performed at various engine speeds (1089 ,1535 ,2050 ,2676 ,3490) RPM to examine how changes in the engine's operational parameters influenced pollutant concentrations. Exhaust gas

samples were collection from the outlet pipe, and their composition was analyzed to determine the reduction in pollutants achieved by the Brass-based system .

Figure 2 Fitting Catalyst

Figure 3 Four Stroke Engine

The experimental data collected from the gas analyzer were compared to analytical calculations of standard emission values. These calculations involved established formulas for estimating the pollutant concentrations based on fuel combustion rates and engine efficiency. By comparing the measured emissions with these theoretical values, the performance of the Brass-based catalytic converter could be quantitatively evaluated. The results demonstrated significant reductions in CO, CO_2 , and HC emissions, particularly at higher engine speeds where the catalytic reactions were most effective.

2.1 Mechanism of the Brass-Based Catalytic Converter

The process begins when the hot exhaust gases, generated by the combustion of fuel in the engine, enter the catalytic chamber. These gases, containing harmful pollutants such as CO, CO_2 and HC, first encounter the Brass core. The core plays a dual role: it acts as a heat sink, stabilizing the temperature of the gases, and exhibits limited catalytic properties that facilitate the initial breakdown of some pollutants. Once the exhaust system reaches this critical temperature, the main catalytic reactions are triggered. The Brass core's honeycomb structure ensures uniform distribution of gases, maximizing their exposure to the catalytic material. Nitrogen oxides (NOx), a major contributor to air pollution, are reduced to nitrogen gas (N_2), a harmless component of the atmosphere. Simultaneously, carbon monoxide (CO), a toxic gas, is oxidized into carbon dioxide (CO_2), which is significantly less harmful. Hydrocarbons (HC), another category of pollutants, are broken down into simpler compounds such as water.

3. Results

The study assessed the performance of a Brass-based catalytic converter in reducing emissions from a 4-stroke engine. Experimental data demonstrated the converter's significant efficiency in mitigating pollutants, highlighting the potential of Brass as a catalytic material

Hydrocarbon Emissions (HC)

The modified catalytic converters demonstrated a consistent and significant reduction in hydrocarbon emissions across all operational conditions. At an Engine Speed of 1089 RPM, HC levels decreased from 626.19 ppm in the standard configuration to 476.2 ppm in the modified system, representing a 24% reduction. The improvement became more pronounced at higher

Figure 2 Hydrocarbon Emission

frequencies, with a 27% reduction observed at 3490 RPM, where HC levels dropped from 299.54

ppm to 218.6 ppm. Similarly, for the single percentage CC, HC emissions were reduced from 460 ppm to 352 ppm, yielding a 23.48% decrease.

Carbon Monoxide (CO)

Carbon monoxide emissions, a critical indicator of incomplete combustion, were significantly lower in the modified catalytic systems. For the Engine Speed-based analysis, CO levels decreased by 27% at 1089 RPM, dropping from 4.05% to 2.95%, and by 21% at 3490 RPM, where CO levels were reduced from 4.98% to 3.95%. The single percentage CC similarly achieved a 20.96% reduction, decreasing CO from 4.466% to 3.536%.

Figure 3 CO Percentage

Carbon Dioxide (CO_2) Production

The modified converters exhibited a marked increase in CO_2 production, reflecting enhanced combustion completeness. At 1089 RPM, CO_2 levels increased by 97%, rising from 4.8% in the standard design to 9.44% in the modified converter. A similar trend was noted at 3490 RPM, where CO_2 production increased by 42%, from 8.67% to 12.31%. For the single percentage CC, CO_2 levels rose from 6.87% to 11.11%, representing a 39.96% increase.

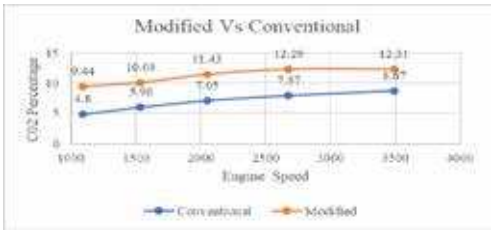

Figure 4 CO2 Percentage

Oxygen (O_2) Concentration

Oxygen concentrations consistently decreased in the modified systems, indicative of improved catalytic activity. In the Engine Speed-based analysis, O_2 levels dropped from 8.35% to 6.46% (23% reduction) at 1089 RPM and from 4.57% to 3.403% (26% reduction) at 3490 RPM. Similarly, the single percentage CC reduced O_2 levels by 25.69%, from 6.1772% to 4.5898%.

4. Conclusion

This study successfully designed and analyzed a honeycomb-shaped Brass-based catalytic converter for 4-stroke engines, demonstrating enhanced emission control compared to conventional catalytic converters. The modified system achieved a 23.48% reduction in HC emissions, a 20.96% decrease in CO levels, and a 39.96% increase in CO_2 concentration, indicating improved combustion efficiency. Beyond emission reduction, the cost-effectiveness and sustainability of Brass make it a promising alternative to expensive platinum-group metal (PGM) catalysts. Traditional catalytic converters cost a minimum of $300, while the

manufacturing cost of the Brass-based catalytic converter is only $99.52—nearly one-third the price. This significant cost reduction, combined with Brass's abundance, recyclability, and durability, allows for wider adoption and frequent replacement, ensuring sustained emission control with minimal economic burden. Future research should examine the impact of Brass-based catalysts on fuel efficiency, backpressure, and long-term durability to provide a more comprehensive evaluation. These findings align with global regulatory goals and the automotive industry's transition to net-zero emissions, reinforcing the potential of Brass as a cost-effective and sustainable material for next-generation catalytic converters.

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